Application-centric, energy-efficient network architecture, ACTION, based on flexible optical network

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***Abstract*—The Compound Annual Growth Rate (CAGR) of Internet traffic volume lies in the 30-70% [1] range. For several good reasons (to handle unexpected traffic spurts, link failures and traffic growth), network resources are significantly over-provisioned in today's networks, and it is quite common to see link utilization in the 30%-40% range [2]. While new optical fibers can be laid, the costs of such deployment should be weighed against the costs of solutions that enable network operation at higher utilization levels. For example, new developments in optical technologies, such as flexible elastic optical networks, enable the provisioning of variable-bandwidth, variable-QoS (Quality of service) transmission pipes. In addition, current and future multi-media services have widely divergent bandwidth and QoE (Quality of Experience) requirements. ACTION (Applications Coordinated with Transport, IP and Optical Networks) is a multi-QoE, application-centric, highly energy-efficient network architecture that leverages flexible elastic optical network technologies. This project is supported by both the NSF, USA, and NICT, Japan, under the JUNO (joint collaboration between Japan and US) program. This paper provides a brief overview of the project.**

Keywords—Quality os Experience, Quality of Service, Quality of Transport, flexible elastic networ

I. Introduction

Rich new content is constantly being added to servers on the Internet, which in turn creates heavy traffic. The networks need to handle flows that have unexpected traffic spurts reaching link capacities, long-duration data-streaming flows, and short flows. Each application type has its own QoS requirements, and traffic characteristics. Data mirroring across physically separate datacenters needs high bandwidth but is usually executed only a few times per day. Streamed video flows generate continuous data and need a minimal bit-rate. Business accounting data flows need high reliability, while gaming applications are major consumers of the Internet best-effort service. Today's Internet supports this varied set of applications by simply over-provisioning links, e.g., 30% - 40% link utilization levels are quite common. However, low network utilization results in low energy efficiency levels, and thus increasing energy efficiency is one of the most important requirements for future network designs.

IP is highly flexible and can handle multiples types of service. TCP enables fair sharing of link bandwidth between concurrent connections with similar round-trip times. On the other hand, the state-of-the-art elastic optical network technology enables dynamic and flexible bandwidth assignment for each wavelength [3-5]. Therefore, it could be used to provide multi-QoS pipes between edge nodes.

In this paper, we propose a new application-centric network architecture based on elastic optical network technology. In the proposed ACTION architecture, edge nodes called Action edges monitor application QoE (Quality of Experience) and assign flows to various multi-QoS (Quality of Service) virtual optical networks. In each virtual optical network, QoS is guaranteed by adjusting elastic optical pipe bandwidth or via multi-route techniques by monitoring optical transmission quality, QoT (Quality of Transport). Multi-QoS virtual optical networks can be created with to meet optical bit-error rate or delay time requirements by considering QoT. Elastic optical networks require consideration of interference between signals on different wavelengths, and hence QoT must be considered.

In the proposed ACTION network, QoS monitoring will be used to identify bottleneck links, and the bandwidth of these links will be changed automatically leveraging the elastic optical network technology. In addition, techniques for automatically aggregating traffic onto small number of links will be designed so that one or more links can be powered off using the MiDORi methods. Therefore, high QoE measures can be achieved while simultaneously ensuring energy efficiency. This is the main objective of ACTION.

II. ACTION Architecture

The Internet is a flexible and scalable network infrastructure, and IP is its best known protocol for supporting different services. However, recent advances have resulted in multi-media flows with highly divergent application characteristics such as traffic rates and holding times, and requirements for QoS measures such as latency and loss-tolerance. The basic principle of TCP is to share the

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bandwidth among multiple connections on each link. However, in large networks, certain links can become bottlenecks on end-to-end paths, as illustrated in Fig.1, while other links remain under-utilized. The throughput of a TCP connection is determined by the rate of the bottleneck link on its end-to-end path.

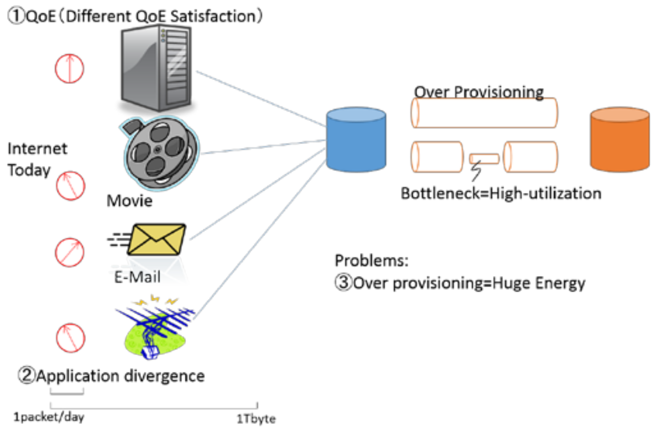

Fig. 1 Problems in today's Internet

To resolve these issues, we propose ACTION, a new application-centric network as represented in Fig. 2. ACTION uses multiple slices of a virtual optical network. Each slice provides a different QoS. The elastic network can create multiple bandwidth pipes between nodes.

ACTION edge nodes monitor each application's QoE. If QoE degradation is detected, the application's flow is mapped to a slice with better QoS automatically. On the other hand, if QoE is well above the required well, a lower QoS slice may be used.

The multi-QoS optical slices are established by the self-sizing elastic network technique as shown in Fig. 2. The elastic network can adjust link capacities easily. All the virtual link utilization rates are monitored, and their bandwidth levels are adjusted to hit the utilization target, for example 70%. With this technique, link bandwidth can be adjusted to traffic levels automatically including parallel routes transmission [6], and hence this techniques is referred to as "self-sizing."

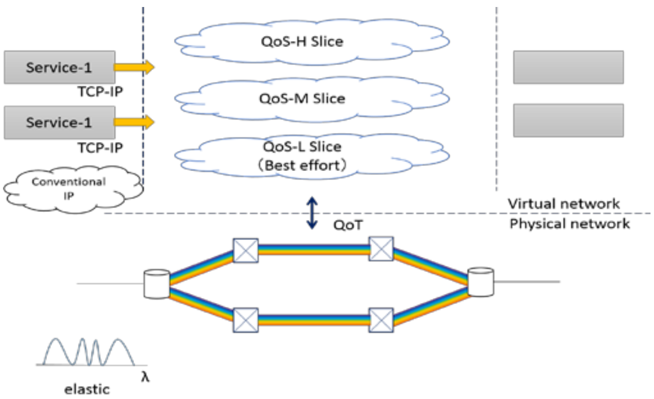

Fig. 2 ACTION architecture overview with multi-QoS virtual optical network slices using elastic optical networks

III. ACTION Edge

The ACTION Edge needs to support TCP/IP. The basic function of an ACTION Edge is illustrated in Fig. 3. The ACTION Edge monitors the QoE of certain applications and modifies the transport network bandwidth automatically if QoE is below the desired level. In the ACTION network, a complete mesh of virtual optical pipes is provisioned between ACTION Edges. Users and application thus enjoy high QoE as the network automatically provides the required bandwidth.

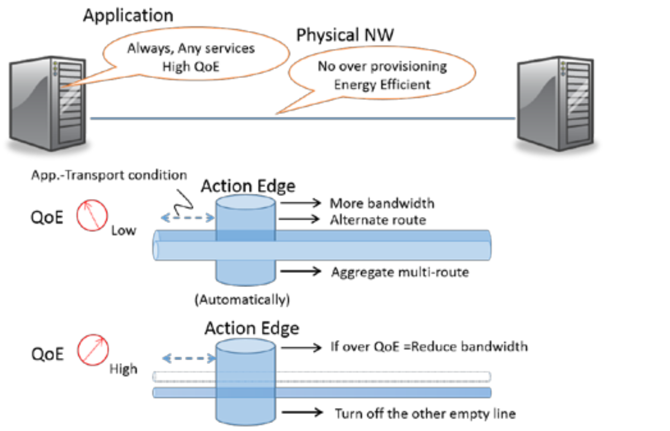

Fig. 3 Function of ACTION edge

Another approach is to map application flows to different QoS slices by each ACTION edge as shown in Fig. 4. This ensures that each application receives its required QoS.

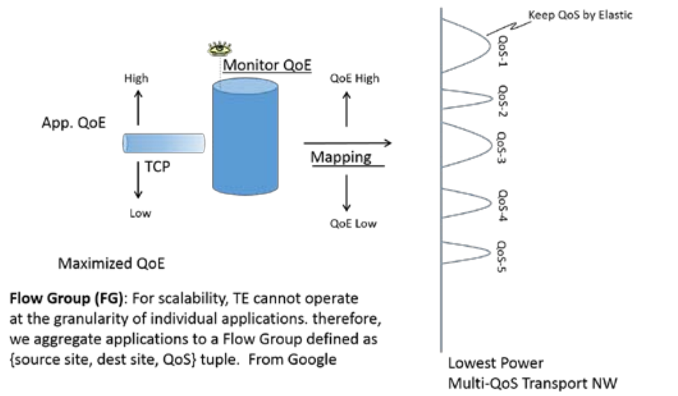

Fig. 4 ACTION edge node assigns each flow to an appropriate QoS elastic optical slice according to its QoE requirement

Open issues:

(1) To monitor all TCP flows between source-destination pairs is difficult especially in high-speed networks. The term α-flow is used for large-sized, high-rate flows [7, 8]. As a first step, we target α-flows for identification and the provision of QoE assurances.

(2) How to obtain the desired QoE for each application? There are two methods: (i) an explicit method using signaling, and (ii) an implicit method by having a proxy function set QoE

values at the ACTION Edge. The sender application can keep increasing the flow rate until the required QoE is met.

IV. Virtual optical slice network

The virtual optical slice network can be created by elastic optical links, as shown in Fig. 5 (a). In addition, multi-route paths can be aggregated into one virtual optical path as shown in Fig. 5 (b). Thus the optical slice network is a logical network with multi-QoS capability. In the optical slice network, the MiDORi technique [9-12] is employed for physical network power consumption reduction. A MiDORi network aggregates multiple traffic flows onto a small number of physical routes, creating unutilized links wherever possible so that the router can power-off the corresponding interfaces. of which are depowered whenever possible.

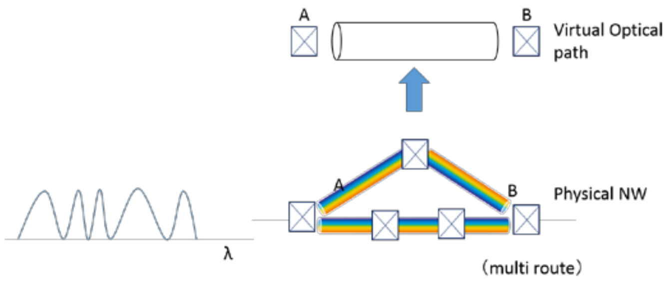

Fig.5 Virtual optical slice having flexible bandwidth

Open issues:

The elastic network uses adaptive modulation coding that depends on distance, bit-rate, and adjacent signal conditions. The Eye diagram is altered by adjacent wavelength signal conditions. We call this the QoT (Quality of Transport). So coordinating QoS with QoT parameters is essential.

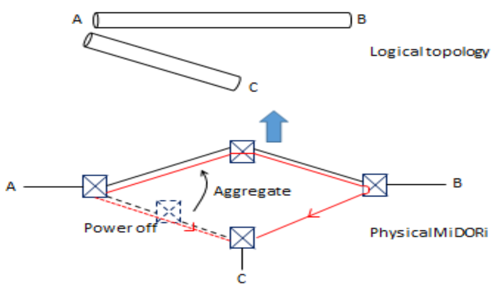

Fig.6 MiDORi technique provides virtual topology with minimum power consumption.

Performance evaluation: An elastic optical network can provide flexible bandwidth optical paths [3,4,5]. Therefore, it is more efficient than a fixed grid network. Our ACTION virtual optical slice can be used to create elastic paths. Figure 7 shows the estimated power reduction achieved by the ACTION network with average link bit-rates of 50 Gb/s and 75 Gb/s relative to the conventional fixed bandwidth network with 100 Gb/s links; the topology assume is the NSFnet. Our evaluation shows that about 20% to 50% energy reduction is possible. We need more detailed studies that take into account device characteristics and design considerations.

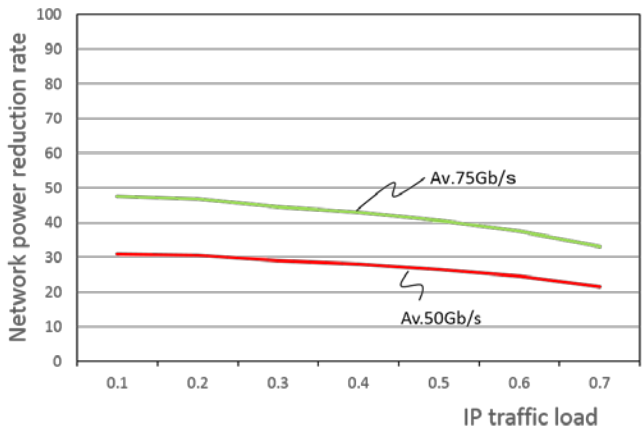

Fig.7 Energy reduction rate of ACTION Network

V. Conclusion

This paper proposed ACTION, a new application-centric network architecture. ACTION uses a dynamic flexible optical sliced network having multi-QoS capability; it employs an elastic optical technique and adaptive traffic aggregation technique first proposed in the MiDORi network. ACTION edge nodes monitor the QoE of certain application flows and maps these flows to the appropriate QoS optical slice. The QoS of each optical slice is monitored, and the route and bandwidth of optical paths are dynamically changed to ensure that QoS requirements are met. The optical transport network is a self-sizing network wherein the bandwidth and route are modified automatically as needed. According to our primary evaluation results, network power can be reduced by about 20 – 50 % using the ACTION network.

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